ARKIV FÖR FYSIK Band 3 nr 18

Read 24 January 1951

Measurements of γ-radiation from the human body

(Preliminary report)

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With 7 figures in the text

Introduction

During recent years there has been an increased need of an instrument with which the γ-radiation emitted by the human body can be measured. This is for two reasons.

One is the necessity of ascertaining at an early stage whether a person working with radioactive substances has been contaminated with such substances. Especially in the case of long-lived elements such as radium and thorium, a possible cumulative storage in the body of radioactive elements must be observed in order to prevent radiation injuries.

The other reason is that the normal amount of ionizing radiation in the tissues is of fundamental importance for estimating the quantities of radioactive isotopes deposited in the body which may be regarded as harmless. Consequently it is of interest to determine the content of radioactive elements, particularly radium, in persons who have not been in contact with substances having an appreciably higher concentration of such elements than the surface of the earth.

With regard to the normal content of radium in human subjects, two papers are of special interest, namely those of Krebs[1] and of Hursh and Gates[2]. They show a marked discrepancy. The former found an average value of $1.4 \cdot 10^{-8}$ g Ra, the latter authors an average of less than $1.5 \cdot 10^{-10}$ g Ra for the total amount stored mainly in the skeleton. Both investigations were made on cremation ashes. The results are assembled in Table 1.

Table 1

Author	Origin of subjects	Number of subjects of age				Total Ra content in 10^{-10} g		
		30–50	50–70	>70	Total	Min.	Max.	Average
Krebs	Germany	0	8	10	18	<10	400	140
Hursh & Gates	Mainly USA	3	10	12	25	0.38	4.3	1.5 (1.2)

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[1] A. Krebs, Strahlentherapie, 72, 164, 1942.

[2] J. B. Hursh and A. A. Gates, Nucleonics, 7, 46, 1950.

Table 2

Source of radiation	Millirem[1] per week	
	Min.	Max.
External sources: Cosmic rays	0.6 (sea level)	0.7 (500 m above sea)
γ rays	0.3 (in nature)	9 (in houses)
Internal sources:		
K 40 content in skeleton 0.06 % K	0.1	
muscles 0.37 " "	0.7	
whole body 0.20 " "	0.4	
Ra in skeleton (50 % Rn assumed to escape from skeleton)		
In cremation ashes: acc. to KREBS	<6	250
acc. to HURSH & GATES	0.25	2.5
Total Ra-content acc. to the author's prel. measurements (25 % Rn ass. to escape from body)	—	100

It is difficult to judge whether there was an actual difference in the radium content of the subjects tested or whether, as HURSH and GATES found probable, KREBS' higher figures may be ascribed to impurities originating from the cremation method.

It is, however, of great value to know what is the magnitude of the normal radium content. If KREBS' average values are correct, the radium must be the main origin of the natural ionizing radiation, at least in the skeleton. If, on the contrary, the value of HURSH and GATES is accepted, the radium content contributes only slightly to this radiation and the γ-radiation from the surroundings plays a relatively more important rôle. This is obvious from Table 2, in which the α-radiation is assumed to have about 10 times higher biological efficiency than the β- and γ-radiation.

From the foregoing it is apparent that investigations with a method for testing living persons with regard to their radium content may be of interest. Such a method has been used by, for instance, HESS and MCNIFF[2] for measuring radium contents of the order of 0.1 ± 0.01 μg Ra.

The apparatus described in the present paper[3] was designed mainly for investigations of persons engaged in work with long-lived γ-radiating substances, principally radium and thorium. Although it has not proved sufficiently sensitive to solve the forementioned question definitely, the experience gained shows that the method is promising. With some improvements it should allow the determination of radium quantities down to amounts of a magnitude below which biological effects of the radium content may probably be disregarded in comparison with those of the other sources of ionizing radiation. The method may be used to advantage together with determinations of radon in the breath.

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[1] Milliroentgen equivalent man (roentgen unit, r, corrected for biological effect).

[2] V. F. HESS and W. T. MCNIFF, Am. Journ. Roentg., 57, 91, 1947.

[3] A report on the apparatus has been given at the meeting of the Scandinavian Society for Medical Radiology in June 1949 and at the 6th Intern. Congress of Radiology, July 1950.

Method and apparatus

The principle of the method is seen from the wiring diagram in Fig. 1. The pressure ion chamber A (25 kg/cm^2, N_2) is built up of 10 tubes, 22 cm in diameter and 125 cm in length, giving a total volume of about 400 l. The central electrodes have guard rings and are connected to the grid of an electrometer tube F and a 10^{12} ohm resistance B. The tubes are charged by means of a perspex-insulated dry battery of 900 V and covered with an earthed casing. They are arranged concentrically around a cylinder 50 cm in diameter, in which the subject to be tested is placed. A berth formed by an aluminium plate with a curvature of approximately 50 cm has been found to be surprisingly comfortable. The time constant for the measuring system amounts to about 5 minutes.

The plate current of the electrometer tube (VX41) is balanced by means of the arrangement H and, when the ionization changes, the out of balance current is recorded on a roll of photographic paper by means of an overdamped ISING[1] toroid galvanometer G_2. A Cambridge spot galvanometer G_1 is used for visual observations.

The operating data of the electrometer tube are very carefully controlled and the apparatus is run continuously for several months.

Because considerable time is required for stabilization, there is a special potentiometer and a contact arrangement D, which can be used when starting the recording. The potential on the earth side of the high resistance G, and the compensation current can be observed accurately (E and I) and are adjusted to a constant value 2–4 times a day. The atmospheric pressure is recorded with a microbarograph in order to be able to correct for slow changes in the cosmic radiation. The temperature of the apparatus is also recorded.

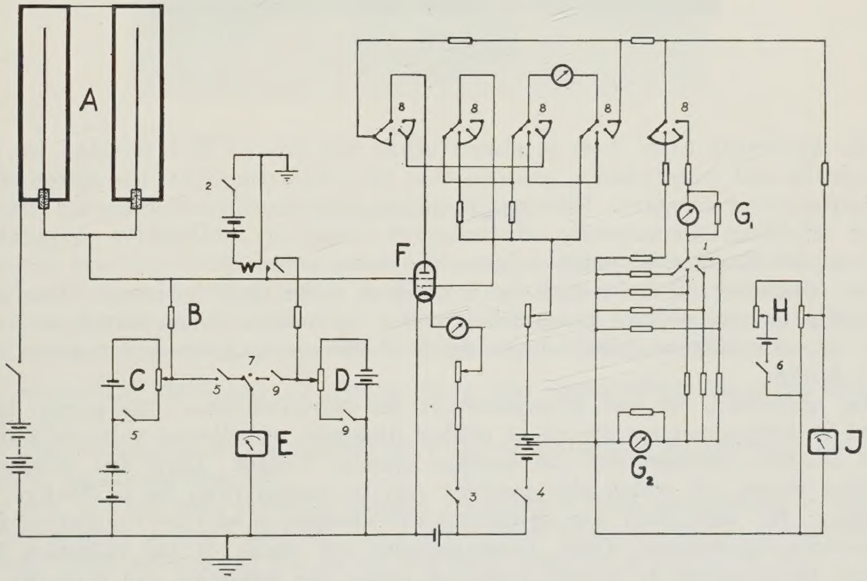

Fig. 1.

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[1] G. ISING, Ark. f. Mat., Astr. o. Fysik, 36 A, 1, 1948.

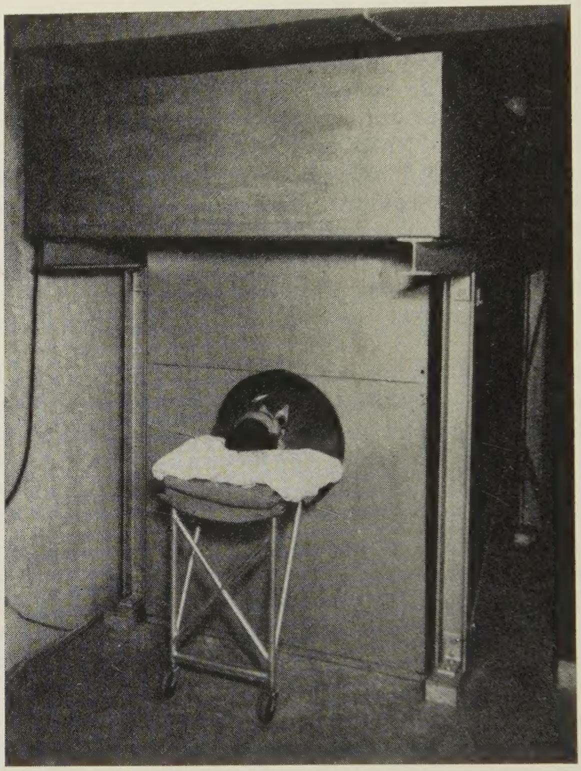

Fig. 2.

The apparatus (Figs. 2–4) is placed below the ground and shielded by concrete walls and water tanks, ensuring that the γ-radiation from the surroundings is comparatively constant. Hitherto, there has been insufficient space for effective water shielding. Occasionally, disturbances caused by radioactive preparations used in surrounding laboratories have also been noted.

The constancy of the sensitivity is checked every night by means of an automatically moving radium preparation of 0.1 μg radium which travels on a wire from its wall-position down to the centre of the ion chambers and remains there for 4 hours.

The absorption of the γ-radiation of the surroundings in the person to be tested is determined by means of rubber dummies of different volumes and the same relative cross-sections as average human bodies. They are filled with distilled water, of which the quantity can be varied from 50 to 75 kg. The dummies are also used for estimating the absorption of the γ-radiation from radioactive substances. Thus, measurements are made of the radiation from radium preparations in various positions inside the dummies and from the normal amount of K 40 (1.5 MeV γ-ray energy), by using solutions of different potassium salts.

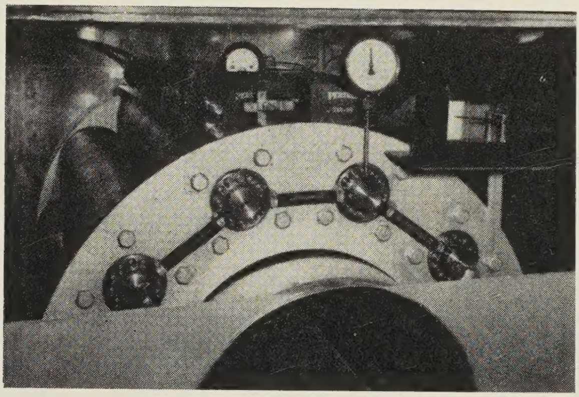

Fig. 3.

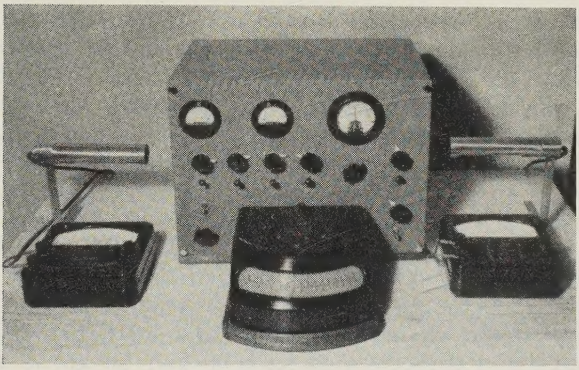

Fig. 4.

Preliminary results

Records are made with the radium preparation, the dummies and the persons to be tested, a zero-record being made between each of them. All these parts of the records are run for at least 2 hours. A typical record is shown in Fig. 5.

The variations which at present limit the accuracy of the method are caused by:

the statistical variations of γ-rays from the surrounding material and of cosmic rays;

the slow variations of the cosmic rays due to changes in atmospheric pressure and other circumstances and

the lack of sufficient shielding against γ-radiation from surrounding material. This necessitates a correction for body absorption of a magnitude corresponding to about 0.055 to 0.08 μg Ra in air for body weights of 50 to 80 kg.

To these sources of errors must be added the uncertainty of the correction for the absorption in the body of the γ-radiation to be measured. This is

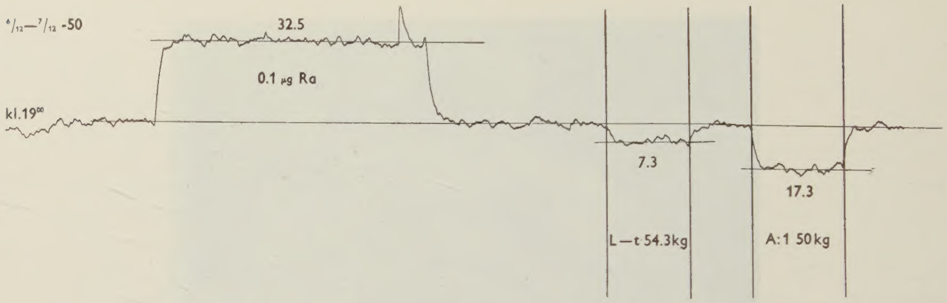

Fig. 5. A typical record showing a calibration deflection with 0.1 μg Ra and two absorption deflections, one with a person having a considerable radium content and one with a water-filled dummy.

difficult to determine on the grounds of the unknown distribution in the body of the radioactive element in question.

Some of the results obtained hitherto are assembled in Fig. 6, which shows the absorption values of the persons tested and of the rubber dummies, divided by the slightly differing values recorded with a standard preparation of 0.1 μg Ra (maximum deviation during about one year ± 5 %). The two lowest curves were obtained by actual measurements. The absorption curve representing the body without γ-radiation is based on more than 50 records made with 50, 60, 70 and 75 kg of water. The 60 kg value was obtained with two dummies of different size (filled to a different extent) giving surprisingly similar results. The curves for 0.01—0.20 μg Ra were calculated with the use of observations of the radiation from a radium preparation of 0.2 μg Ra in different positions in a dummy. These equidistant curves representing the radium content in the skeleton may have a maximum uncertainty of ± 15 % for the absolute values and are not corrected for excretion of radon and for K 40. The curve for K 40 (140 g K) was calculated from records with 50 and 70 kg of water containing about 3 kg of KNO_3 per 70 kg. The average content of potassium in the body was assumed to be 0.20 per cent.[1] Salts of different origin were tested. The present values must be regarded as provisional, since a purification of the salts for eliminating traces of radium will later be made. However, a test with an α scintillation counter gave negative results.

Under favourable conditions, the standard error can be reduced to ± 0.002 μg Ra eqv. with 6–8 observations for persons with no radioactive contamination. There may, however, be systematic errors of at least the same order of magnitude, caused mainly by the difference in absorption in the dummies and the experimental subjects and by the unknown distribution of the radium in the body.

The data for the persons tested are shown in Table 3 ("normal persons") and Table 4 (persons having been in contact with radioactive material). In the latter case precautions were taken to avoid the presence of surface contamination. Careful controls were therefore made with an α scintillation counter.

As is obvious from Fig. 7, there seems to be an increase in the probable radium content with increasing age. The results must, however, be regarded as com-

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[1] A. T. SHOHL, Mineral Metabolism, Am. Chem. Soc. Monograph, Ser. 82, 1939.
L. CORSA Jr, J. M. OLNEY Jr, R. W. STEENBURG, M. R. BALL and F. D. MOORE, Journ. Clin. Invest. 29, 1280, 1950.

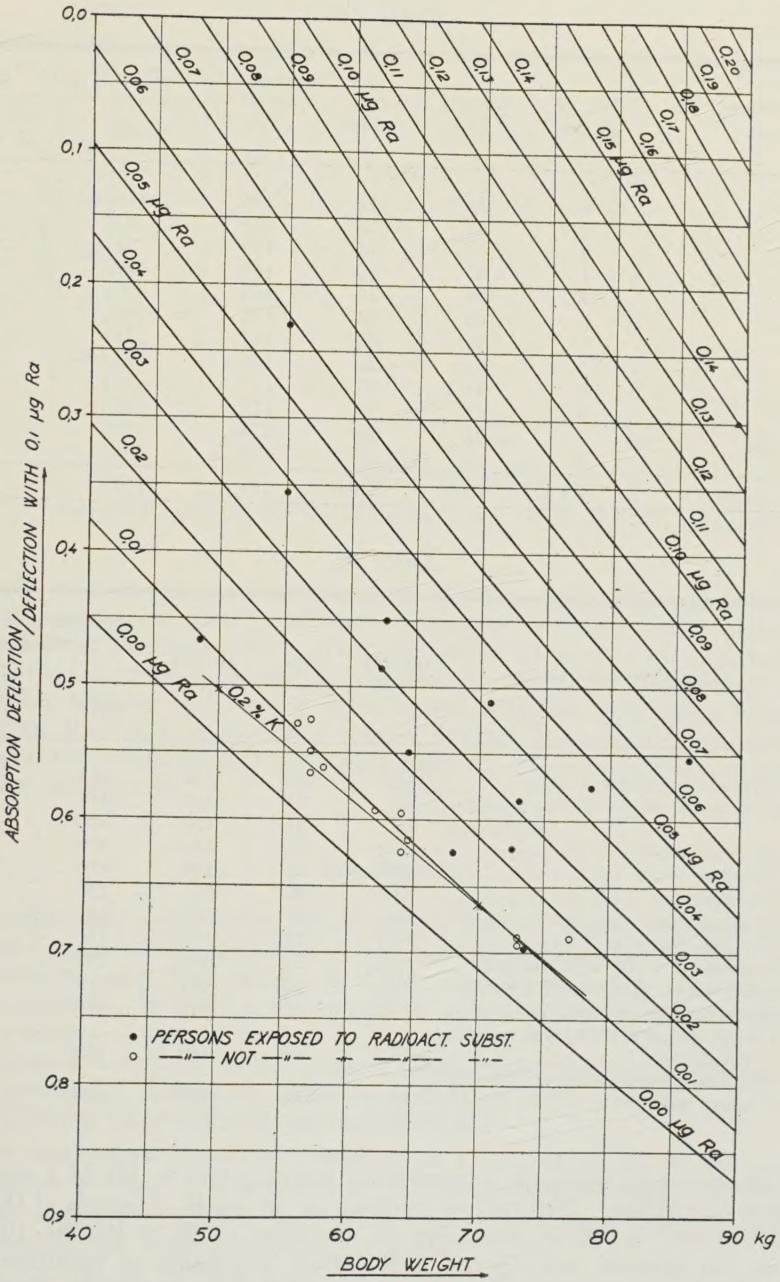

Fig. 6. The method of using the relative values of the absorption deflection is obvious from Fig. 5.

Table 3

Person no.	No. of observ.	Weight kg	Age years	Length cm	γ-radiation in 10^{-10} g Ra eqv.	
					Total	Per 70 kg of weight
n 1	3	56	31	165	114	142
n 2	2	57	23	164	67	82
n 3	2	57	15	170	93	114
n 4	1	57	43	157	137	168
n 5	7	58	19	163	90	109
n 6	5	62	25	173	92	104
n 7	1	64	27	171	71	78
n 8	1	64	48	164	124	136
n 9	8	64.5	27	171	96	104
n 10	2	73	25	175	86	83
n 11	5	73	23	174	97	93
n 12	7	77	58	176	165	150
Average:	3.7	63.6	30.3	168.6	103	114

Table 4

Person no.	Working conditions	Weight kg	Age years	Length cm	γ-radiation in 10^{-10} g Ra eqv.	
					Total	Per 70 kg of weight
1	Radium work for 1 year[1]	48.5	25	154	95	137
2	Lum. comp. (Ra) work for: 3 years	55	31	157	385	490
	3.6 years	55	31	157	590	750
3	Thorium work for 15 years	62.4	64	182	300	335
4	Thorium work for 1 year	62.7	36	159	370	415
5	Uranium ore work for 1 year	64.5	40	167	220	240
6	Uranium ore work for 3 years	68	36	166	140	145
7	Thorium work for 1 year	70.7	38	168	410	405
8	Occasional work with radium[1]	72.5	23	176	230	220
9	Lum. comp. (Ra) work for 8 years	73.4	32	171	310	295
10	Occasional work with radium[1]	73.5	32	174	90	86
11	Periodical work with large radium quantities[1]	78.5	36	180	450	400
12	Occasional work with radium for many years[1]	86.5	62	171	680	550

paratively uncertain since the observations are too few to afford a statistically significant correlation. The radium content at 50 years of age is of the magnitude of $60 \cdot 10^{-10}$ g Ra or, assuming an excretion of 25 % Rn, $80 \cdot 10^{-10}$ g Ra. According to HURSH and GATES' calculation, supposing a retention of 2 %, this would correspond to an average content in the water intake during life of $10–20 \cdot 10^{-15}$ g per ml which, for Swedish conditions, seems to be a reasonable value.

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[1] Open radium preparations.

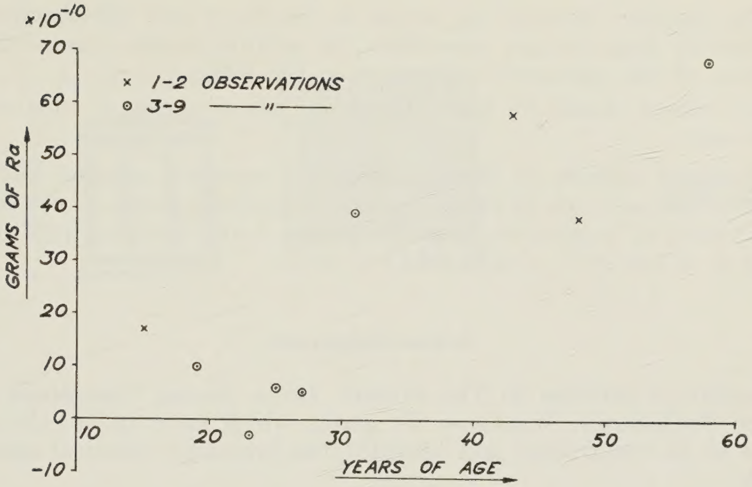

Fig. 7. γ-radiation corrected for the radiation due to K 40 but not for excreted Rn.

Already after a few years some persons working with radium or thorium show a marked increase in their γ-radiation. Frequent testing of such persons must be regarded as necessary. It is often impossible to state why a certain person has absorbed a greater amount of radioactive substances than others working in a similar manner and coming into contact with the radioactive substance in question to the same, or even to a greater, extent. Presumably, small differences in the working technique and hygienic conditions, which cause the contamination, have been overlooked.

Conclusions

The preliminary observations show with a certain degree of probability that, as Krebs[1] has already pointed out, the radium content in the body increases with increasing age. The values of Hursh and Gates[2] may be representative for the conditions in their subjects but do not seem to be in contradiction to Krebs' results.

The method described in the present paper could not be fully utilized owing to the presence of disturbing radiation and other circumstances.

The following improvements are recommended.

1. The apparatus should be installed in a laboratory below the surface of the earth, at a depth giving sufficient protection against the cosmic rays.
2. The laboratory should have walls (water) providing adequate protection against γ-radiation from surrounding material.
3. The air should be free from radioactive substances, and the temperature constant.

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[1] A. Krebs, Fundam. Radiol. 5, 89, 1939.

[2] J. B. Hursh and A. A. Gates, loc. cit.

4. The distance between the person to be tested and the chambers should be sufficiently large to give approximately uniform results, irrespective of the distribution of the radioactive substance in the body.

5. Each record should be made during as long a period of time as possible (e.g. 4 hours).

If all contact surfaces of the apparatus are correctly designed and the construction is also adequate in other respects, it appears possible to use the method for observation of γ-radiation from the human body down to quantities corresponding to a few 10^{-10} g of radium.

Acknowledgments

The author is indebted to *The Swedish Atomic Energy Commission* and *Knut and Alice Wallenberg's Foundation* for grants which have enabled the apparatus described to be constructed and provided the necessary technical assistance for the work.

The Institute of Radiophysics, Stockholm, January 1951.

Tryckt den 22 juni 1951

Uppsala 1951. Almqvist & Wiksells Boktryckeri AB